BETT TTEB

Case Study of a New Warehouse

A RESEARCH REPORT

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The Buildings Energy Technology Transfer Program (BETT) of EMR has been created to assist building owners, users and practitioners active in the design, construction and operation of buildings in identifying technical obstacles to energy conservation. Through a nationwide network of research agencies and private sector consultants, BETT carries out research and development projects and provides the audiences mentioned above with technical reports, how-to manuals, training manuals, audio-visual aids and data bases to help them overcome these obstacles.

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ABSTRACT

Warehouse and light industrial buildings constitute a major building category in Canada. Little attention has been focused on conserving energy or reducing operating costs in these buildings. The category can be subdivided into owner-occupied and leased buildings. The design/build companies that serve a substantial portion of this market are forced by market pressure to offer buildings at low first cost, precluding the more expensive construction necessary to achieve energy efficiency. Owner/users are relatively uninformed as to the cost/benefit relationships existing for many conservation measures, although it would be in their interest to have this data. Owners who intend to lease the buildings they construct are even less concerned with future operating costs because of the 'net' leasing agreements which are prevalent.

This case study deals with a relatively new warehouse built in early 1980 which is reasonably typical of recent such buildings, although certain conservation features were included. Based on the actual monthly energy consumptions, a computer-based analytical model was used to match the subject building usage and cost. From this, a base or standard building was simulated which excluded the conservation features of the subject building. Several design modifications to the roof, walls and lighting system were examined, along with operational modifications. For all these conservation modifications, the energy and dollar savings are shown as well as the estimated first cost premiums.

RÉSUMÉ

Les bâtiments d'entreposage et les bâtiments industriels à structure légère constituent une catégorie importante au Canada. Peu d'attention a été accordée sux économies d'énergie dans ces bâtiments ou à la réduction de leurs frais d'exploitation. Les bâtiments de cette catégorie peuvent se subdiviser en bâtiments occupés par le propriétaire et en bâtiments loués. Les constructeurs et architectes qui desservent une partie importante du marché doivent, pour trouver acheteur, concevoir des bâtiments à prix coûtant peu élevé, ce que ne leur permet pas de procéder à des travaux de construction plus coûteux qui assurent un bon rendement énergétique. Les propriétaires qui ont l'intention de louer les bâtiments qu'ils font construire se préoccuppent encore moins des futurs coûts d'exploitation, qu'ils peuvent intégrer aux contrats de location-bail, dont l'usage est très répandu.

La présente étude porte sur un entrepôt relativement neuf, puisqu'il a été construit vers le début de 1980, et qui est assez représentatif d'entrepôts de construction récente, quoique sa conception incorpore certaines mesures d'économie d'énergie. Un modèle analytique réalisé à l,aide de l'ordinateur et basé sur les chiffres réels de la consommation mensuelle d'énergie du bâtiment a servi mettre en parallèle le mode d'utilisation et les coûts correspondants, À partir de ces données a été simulée la construction d'un bâtiment de référence n'incorporant aucune des mesures d'économie d'énergie intégrées au bâtiments réel. Plusieurs modifications apportées à la conception du toît, des murs, et du système d'éclairage, ainsi que des modifications de fonctionnement ont été examinées. On trouvera exposées dans le présent rapport les économies d'énergie et d'argent réalisables grâce à toutes ces modifications, ainsi qu'une estimation des suppléments au prix coûtant.

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The Buildings Energy Technology Transfer Program (BETT) was initiated by the Department of Energy, Mines and Resources (EMR) of the Government of Canada in late 1981. The principal objectives of this program are:

- to identify the potential for energy conservation in both new and existing buildings
- to determine R, D and D requirements and their priority in order to exploit this potential
- to perform and/or expedite the necessary R, D and D
- to effectively transfer the necessary technology to the appropriate individuals, groups or agencies
- to provide technological support to EMR in the development of policy and programs.

The Building Engineering Group (BEG) was selected* by EMR to develop and execute a comprehensive R, D and D program for energy conservation in the warehousing and light industrial building sector. BEG is a semi-autonomous, non-profit agency associated, through the Waterloo Research Institute (WRI), with the University of Waterloo. This multi-disciplinary group attempts to provide a comprehensive range of R and D services to the building industry.

The warehouse and light industrial building sector is particularly important because:

- the square footage of building space encompassed by this category is second only to that of the residential building category
- to date very little R and D, energy-related or otherwise, has been directed towards this building category
- the nature of these buildings, both new and existing, makes them particularly amenable to some degree of energy conservation.

* DSS Number 02SQ.23380-1-6665-4 Serial OSQ81-00137 and Proposal Number WRI 109-01, September 20, 1981

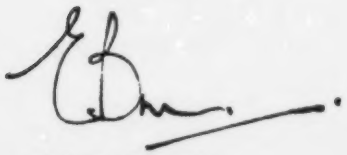
In the initial phase of the R, D and D program developed by BEG, the priorities were to:

- establish a statistical profile of the building category
- develop a comprehensive review of the current state of practice
- initiate the development of a portfolio of representative case histories.

Ten related studies are being undertaken in this initial phase. Seven of these studies provide either supporting documentation or input for a comprehensive state-of-practice report.

This report entitled "Case Study of a New Warehouse" has been prepared by Glenn Steel of Moffat Engineering Limited. It is one of two case histories being prepared within this phase of the project. This case deals with a relatively new warehouse that is representative of current standards and practices within the industry. The active co-operation of Provincial Industries Limited of Brampton is gratefully acknowledged. The building was designed by Inducon Consultants of Canada Limited and their assistance and collaboration in this project was particularly appreciated.

This report is an early product of what is intended to be a concerted multi-year program of research, development, demonstration, dissemination and evaluation. Feedback with regard to the report or related issues is welcomed and should be directed to the undersigned.



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1.1 Background

Warehouse and light industrial buildings constitute a major building category in Canada. They represent the second largest built space after residential and consume significant quantities of energy.

Generally speaking, these buildings are classified as weather dependent; that is, their energy consumption depends to a large extent on the climatic conditions to which they are exposed.

Little attention has been focused on methods of reducing energy consumption in these buildings. Until a few years ago, most of these structures were put up with complete disregard for operating energy costs. While a few changes have been made recently, mostly to the envelope, the market still requires a low first cost. Conservation features included in the original design usually increase first cost.

Companies that design, develop and build serve a substantial portion of this market. To be competitive, they initially propose a "bare bones" building to the owner which, because of market evolution, may contain a few energy-conserving features which have become nearly standard in the trade. Subsequently, depending on the owner, certain other features may be included at additional cost. If the owner leases the building, operating costs are normally paid by the lessee. The owner does not have to pay the energy bills. In addition, market pressure to keep rental charges per square foot low reinforces the owner's need to keep first costs to a minimum.

Canada has, for the most part, been insulated from the effects of the escalation in world oil prices until very recently. This, combined with the fact that we have an abundant source of natural gas in Western Canada, has meant that there has been little incentive to reduce energy consumption where it is not a major cost consideration. For the owner/user of warehouse and light industrial buildings, there are cost effective measures which should be taken during design and construction to reduce future energy use.

In addition to the past lack of economic incentive, there are at least two problems associated with achievement of energy efficiency in warehouse and light industrial buildings constructed for the owner/user. Firstly, owners are relatively uninformed as to the cost/benefit relationships existing for many conservation measures. The lack of definitive data has probably contributed to their lack of interest in incorporating additional cost features at design time. Secondly, the capital cost associated with erecting the structure is divorced from the future operating cost in most financial justifications. Life cycle costing is seldom used in the financial analysis, perhaps because of the lack of understanding of the cost/benefit relationships.

Owners who intend to lease out the buildings they construct are even less concerned with future operating costs than owner/users because of the "net" leasing agreements which are prevalent. Under this arrangement, the tenant pays for (among other things) the operating costs, based usually on the leased area. Since the tenant/user pays the bills, any economic incentive for the owner to reduce energy costs is lost, and no demands are placed on the designer/builder to improve energy efficiency. If users are to be motivated to pursue energy efficiency in leased buildings, they first must be aware of how certain features, which will increase their rental costs, will also reduce their operating costs and to what extent. A demand for energy efficiency by the user will have to be transmitted via the marketplace to the owners and then back to the designer/builder. This indirect process is a more formidable problem than in owner/user buildings and many other market pressures cause this feedback to be ineffective.

Two case studies have been prepared to illustrate the nature of warehouse and light industrial buildings and to demonstrate the various energy related considerations. One case deals with an existing older building which has been retrofitted to increase its energy efficiency. It is presented under separate cover. This report presents a case study dealing with a relatively new warehouse, built in early 1980. The basic details are as follows:

Owner:	Provincial Industries Ltd.
Location:	Brampton, Ontario
Size:	3800 square meters (40,900 square feet)
Usage:	Warehousing, plastic moulding with 372 square meters (4,000 square feet) of office space.
Designed by:	Inducon Consultants of Canada Ltd.
Type:	Single storey with 6.7 meters (22 feet) of height to bottom of roof structural steel, undivided internally except for the office space.

The subject building is reasonably typical of many structures built across Canada in industrial parks and elsewhere. A large percentage is constructed or owned by small businesses with minimum capital available, dictating that the structure be built at the least possible initial cost. Buildings constructed for this market follow a certain pattern in their design and specification, and that pattern also carries over to other buildings of similar end use.

1.2 Objectives

The main objectives of this case study are:

(i) to identify a representative example of a warehouse which was built recently and generally typifies these structures

(ii) to document and quantify the energy related design decisions

(iii) to quantify and compare other possible design options.

1.3 Scope

The dimensions, features and structure of the case study or subject building are documented. A base or standard building is described which matches the subject building in size and usage but differs in construction to typify a structure with the lowest practical first cost.

Both buildings are analyzed from an operating energy standpoint, and their performance is compared. Various other design options are described and compared with regard to their first cost premium and operational consequences.

2.1 Subject Building

Illustrations 1,2,3 and 4 are photographs of the building exterior. Illustration 5 is a floor plan.

General:

Warehouse area - 3428 m^2 (36,904 sq. ft.)

Office area - 372 m^2 (4000 sq. ft.)

Mezzanine area above office - 372 m^2 (4000 sq. ft.)

Clear height - 6.7 m (22 ft.) to bottom of structural steel.

Construction:

Walls
Warehouse- Precast concrete panels with 50 mm (2 in.) polystyrene core.

Office- Brick and precast.

Roof - 4 ply asphalt and gravel on 50 mm (2 in.) fiberglass insulation.

Glazing -
Warehouse- None.

Office- Tinted double glazing.

Doors -
Front Entrance Office - Aluminum frame with 6 mm. (1/4") plate glass.

Warehouse Mandoors - Insulated hollow metal weatherstripped.

Shipping Doors- Insulated steel sectional 3 - 2.4 m x 2.6 m x 45 mm (8'-0" x 8'-6" x 1 3/4") with truck seals. 1 - 3.7 m x 4.3 m x 45 mm (12'-0" x 14'-0" x 1 3/4') drive-in door. Illustrations 6 and 7 are photographs of the exterior and interior of these doors.

Services:

Warehouse Heating - Suspended gas fired unit heaters individually thermostatically controlled to maintain 20°C (68°F) interior temperature. Illustrations 7 and 8 show these heaters.

ILLUSTRATION 1
BUILDING FRONT/LOOKING FROM EAST

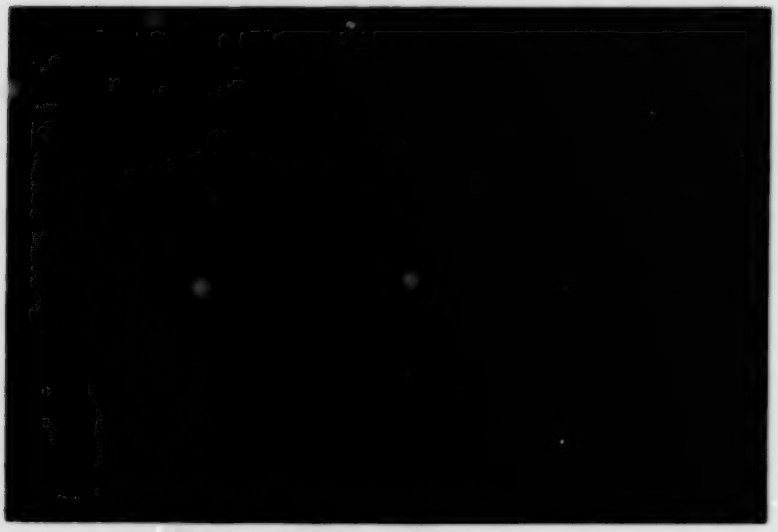


ILLUSTRATION 2
BUILDING FRONT/LOOKING FROM NORTH/SHOWING FRONT
ENTRANCE AND OFFICE WALL CONSTRUCTION

ILLUSTRATION 3
VIEW OF BUILDING FROM WEST

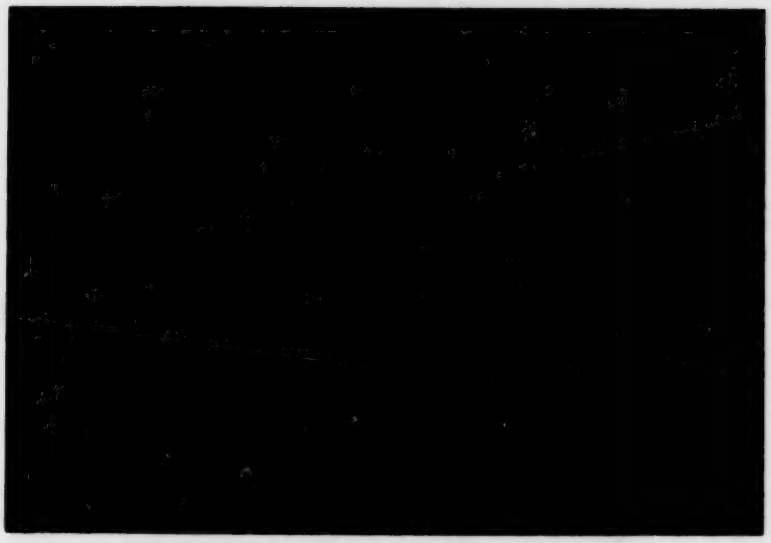
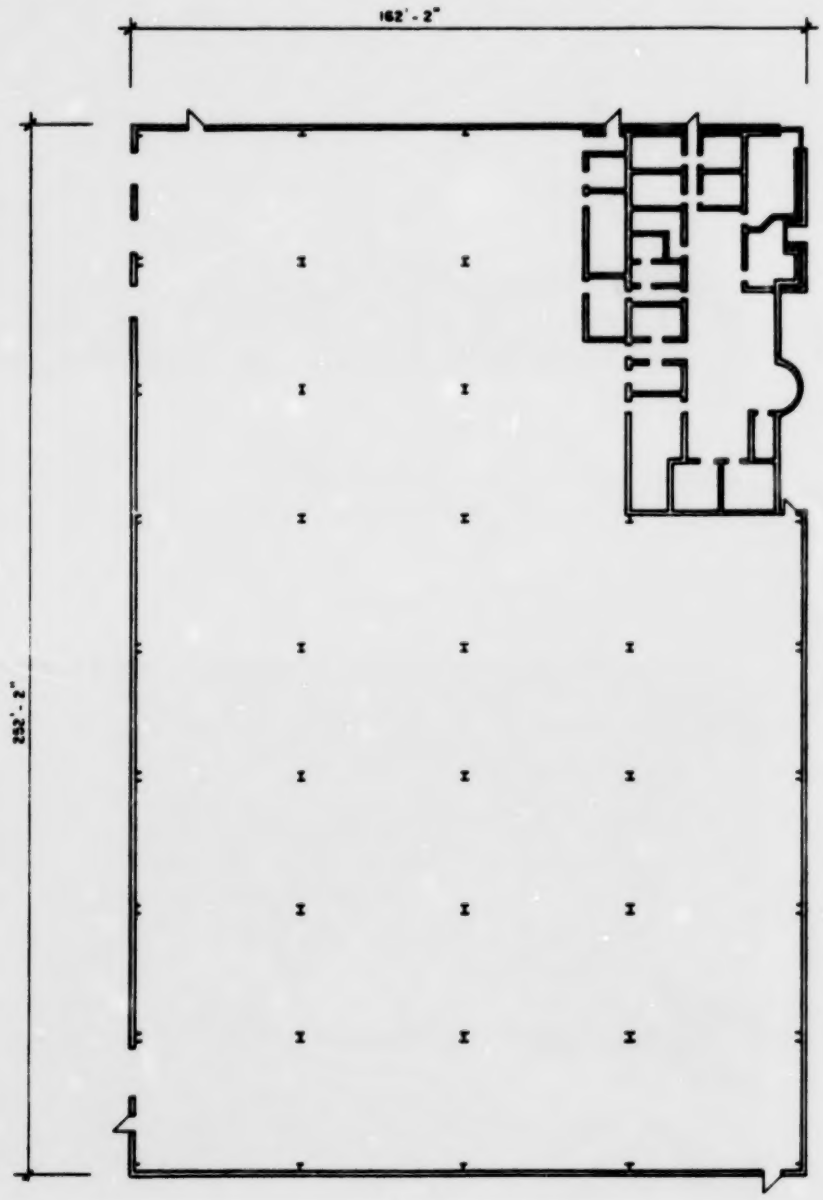


ILLUSTRATION 4
REAR OF BUILDING/SHOWING SHIPPING DOORS



FLOOR PLAN

SCALE 1" = 40'-0"

ILLUSTRATION 5
BUILDING FLOOR PLAN

ILLUSTRATION 8
GAS FIRED UNIT HEATER (TYPICAL)

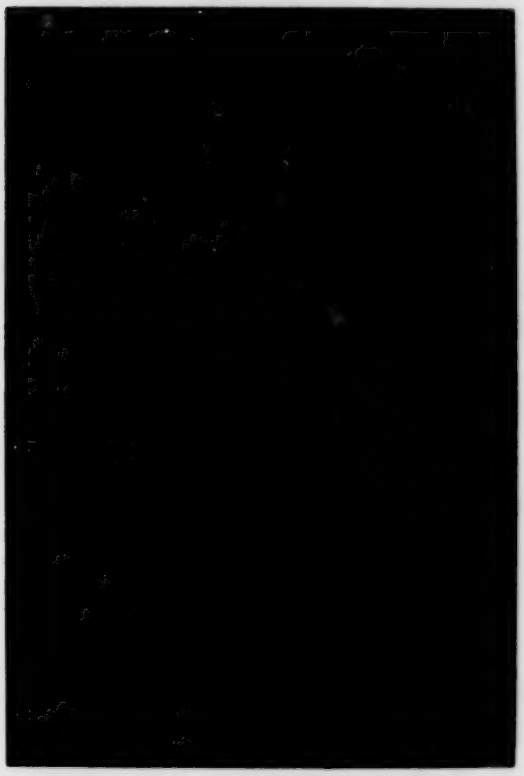


ILLUSTRATION 9
DOWNDRAFT FAN OVER SHIPPING DOOR

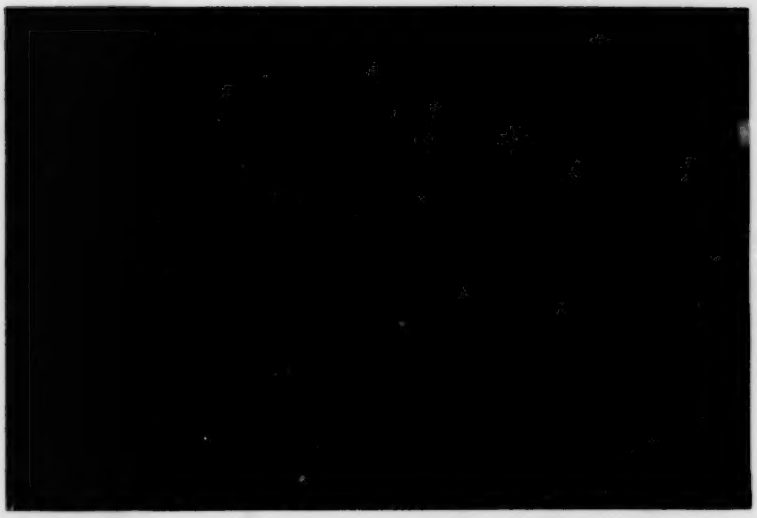


ILLUSTRATION 6
SHIPPING DOOR EXTERIOR

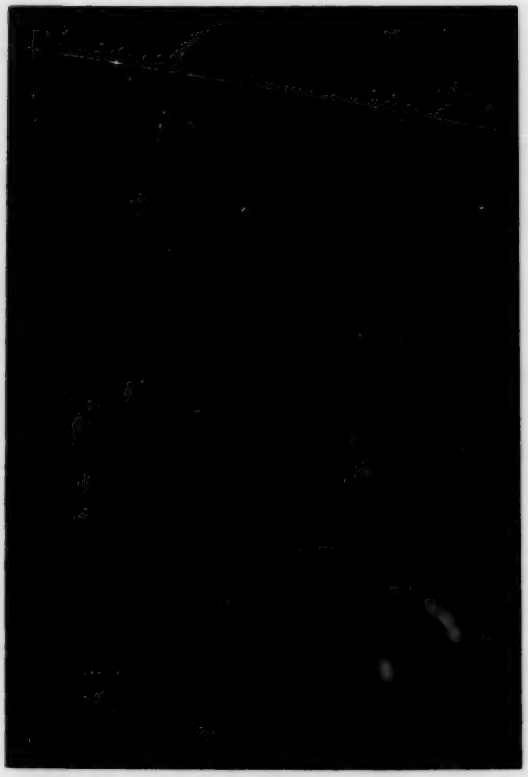


ILLUSTRATION 7
SHIPPING DOOR INTERIOR (TYPICAL)

Office Heating and Air Conditioning - Roof mounted combination gas heating, electric cooling with supplementary electric baseboard heaters to maintain interior temperatures at 23.8°C (75°F)in summer and 22.2°C (72°F) in winter.

Lighting -
Office- 861 Lux (80 foot candles) using 0.6m x 1.2m (2'x4') recessed fluorescent fixtures.

Warehouse - 1858 m^2 (20,000 sq. ft.) at 269 Lux (25 foot candles). 1486 m^2 (16,000 sq. ft.) at 538 Lux (50 foot candles) using 2.4m (8ft) x 2 tube fluorescent suspended fixtures with reflectors.

Other - Downdraft fans at shipping and receiving doors. Illustration 9 shows these fans.

2.2 Base/Standard Building

There are a number of features about the subject building which represent improvements from an energy efficiency point-of-view over what is generally considered a base building. These features are described below, and the base building construction is identified.

Roof

For many years, the standard accepted insulation in the roof was 25 mm (1 in.) of mineral fiberboard giving a total nominal "R" value* of 0.72 (4.1). This is considered the base building roof in this study. In recent years, evolution in the design has produced more buildings with 50 mm (2 in.) of fiberglass, giving a total nominal "R" value of 1.50 (8.5), as is the case in the subject building.

Walls

The subject building has exterior walls constructed of precast concrete panels with a 50 mm (2 in.) thick polystyrene core. The total "R" value is approximately 1.58 (9.0).

*R value is a measure of the thermal resistance expressed in m^2 °C/W (ft.^{2} °F.hr/BTU)

Standard wall construction is 300 mm (12 in.) concrete block with an "R" value of 0.37 (2.1). Often, architectural block is used to satisfy local bylaws and the thermal resistance is approximately the same. Where interior clear heights exceed 5.5 m (18 ft.), precast panels or metal siding become economical. The addition of 35 to 75 mm (1.5 to 3 in.) of insulation to this type of wall can be accomplished with minimum increase in cost. In the case of precast concrete panels, it is now standard practice to include insulation.

Windows

The warehouse area in the subject building contains no window sections at all. Although this improves the thermal resistance of the wall substantially, the reasons for excluding windows are often related to security, vandalism and first cost. When windows are specified, it is normal to use single glazed units in the warehouse walls with an "R" value of 0.16 (0.9). Compare this with the subject building wall resistance of 1.58 (9.0). Office window areas are double glazed with an "R" of 0.28 (1.6). The base building also has no warehouse windows.

Shipping Doors

Insulated steel sectional doors of 44 mm (1.75 in.) thickness are used, with an "R" value of 0.44 (2.5) compared to 0.33 (1.9) for a 44 mm (1.75 in.) wood panel door. This provides an improvement in thermal resistance over commonly supplied doors. We have not altered the doors for the base building.

2.3 Energy Usage

The subject building is heated almost entirely by natural gas, with some supplementary electric baseboard heating in the office area to overcome cold wall effects at the windows. For the purposes of this analysis, we have ignored the electric heating portion, which is small, and have considered the total natural gas consumption as indicative of the heating costs.

Based on monthly records, gas consumption for the period from February, 1981 to February, 1982 was 62,600 cubic meters (2210 thousand cubic feet) at an average price of $0.146 per cubic meter ($4.14 per thousand cubic feet). The total heating cost for the warehouse was $9,200.

The energy consumption of this warehouse was modelled using a computer program.* Knowing the actual annual consumptions made it possible to adjust the thermal characteristics to conform to the consumption data.

Building operation was modelled on an occupied schedule from 7 AM to 5 PM for 5 days per week with a maintained indoor temperature of 20^{o}C (68^{o}F) at all times during the winter months. Indoor lighting at 10.8 watts per square meter (1 watt per square foot) average is left on all the time. Infiltration of outside air through cracks and through open doors was estimated at 4.6 cubic meters per hour per square meter (0.25 cubic feet per minute per square foot) of wall area. Mechanical ventilation was included at 34 cubic meters (1200 cubic feet) per minute during occupied times and zero when unoccupied.

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*Carrier Program Package using TRS80

In comparing the performance of this building with that of a speculative building (i.e., base building), we identified two features that have a large impact on the consumption of energy for space heating. These are the 50 mm (2 in.) of fiberglass roof insulation and the 50 mm (2 in.) of polystyrene wall insulation. If this same building were constructed using the previously accepted standard of 25 mm (1 in.) of mineral fiberboard in the roof and 300 mm (12 in.) concrete block walls with no insulation, the energy consumption would have been 134,500 cubic meters (4750 thousand cubic feet) of natural gas at a 1981/82 cost of $19,700.

For the sake of accuracy , it should be noted that the above annual cost was projected on the basis of the unit cost for natural gas as incurred in that year. In fact, the cost would have been 3% or 4% lower due to the gas block billing structure. This structure provides a lower average unit cost for higher consumption.

Nonetheless, it is clear that the construction of the subject building provided a saving in excess of $10,000 for the 1981/82 year. This constitutes a substantial recurring real savings in operating cost - a saving that in real economic terms is likely to increase each year.

It is estimated that the difference in initial capital cost at today's prices between the base and subject buildings is $85,800. In terms of simple unadjusted payback, it would take an owner/occupier in excess of eight years to recover this cost. Without considering the improved building appearance, the economics alone are not favourable. For the developer/builder, unless there were some premium for finish or aesthetics that could be realized in the rent, it is unlikely that this would be considered an attractive economic tradeoff in most cases.

Generally, it can be stated that energy efficiency should be considered at the design and construction time since, thereafter, the economics of certain changes reduce the possibilities substantially. This is particularly true of this category of building and, unfortunately, is generally at odds with reality today. The following discussion is intended to show the economics of certain options to improve energy efficiency in the case study building.

3.1 Roof Construction Options

The addition of insulation to the roof structure of these buildings has been studied, and Table 1 shows the savings in natural gas and in current year (1981/82) dollars. Table 1 also shows the estimated difference in construction cost.

A. Substitution of 50 mm (2 in.) of fiberglass insulation in the roof saves $4,600 in the current year at an estimated first cost increase of $19,200.

B. Substitution of 75 mm (3 in.) of fiberglass roof insulation saves $6,140 in the current year compared with the basic building roof at an estimated first cost increase of $36,800.

3.2 Wall Construction Options

Several alternate wall constructions used in this type of building have been compared with 300 mm (12 in.) uninsulated concrete block walls. (base building). Table 1 shows the estimated savings in natural gas and current year dollars as well as the first cost premium associated with each wall type.

A. Masonry wall constructed of 200 mm (8 in.) autoclaved concrete block and faced with 100 mm (4 in.) common brick. "R" value is 0.51 (2.9). This type of wall construction is often legislated in certain areas for aesthetic reasons.

B. Masonry wall, as above, to 2.0 m (6'-8") height with metal panels over insulated with 38 mm (1 1/2 in.) of fiberglass. "R" value is 1.1 (6.0).

C. 12" concrete block having the core voids filled with vermiculite insulation. Although the return on investment for this construction is reasonably favourable, a note of caution should be added. The insulating value for this wall depends on the complete filling of all core voids with insulation and assumes that the vermiculite stays dry. Careful workmanship during wall erection is required, and the exterior surface of the block should be treated with a sealer. "R" value is 0.76 (4.3).

D. Precast concrete panels constructed of 75 mm (3 in.) of concrete on both sides of a sandwiched slab of 50 mm (2 in.) styrofoam. "R" value is 1.58 (9.0).

E. Cavity wall of 200 mm (8 in.) autoclaved concrete block and 100 mm (4 in.) common brick with a 50 mm (2 in.) cavity filled with fiberglass insulation. "R" value is 1.80 (10.2).

TABLE 1: DESIGN MODIFICATIONS TO ROOF AND WALLS
COMPARISON OF SAVINGS AND FIRST COST PREMIUM

MODIFICATIONS TO BASE BUILDINGS HAS 12" CONCRETE BLOCK WALLS, 1" FIBERBOARD ROOF INSULATION, NO NIGHT SETBACK, LIGHTS ON AT ALL TIMES	REDUCTION IN ANNUAL ENERGY USE & COST			ESTIMATED FIRST COST PREMIUM $	SIMPLE PAYBACK PERIOD YEARS
	MCF GAS	M^3 GAS	$		
ROOF					
A. 50 mm (2") fiberglass roof insulation in place of 25 mm (1") fiberboard	1,110	31,500	4,600	19,200	4.2
B. 75 mm (3") fiberglass roof insulation in place of 25 mm (1") fiberboard	1,480	42,000	6,140	36,800	6.0
WALLS					
A. Brick and block wall- 100 mm (4") brick & 200 mm (8") block	400	11,300	1,650	69,200	41.9
B. Brick and block wall to 2.0 m (6'8") height, insulated 38 mm (1.5") fiberglass metal panels above	1,150	32,600	4,770	60,100	12.6
C. 300 mm (12") concrete block, cores filled with vermiculite	960	27,200	3,980	19,500	4.9
D. Precast concrete wall panels with 50 mm (2") of polystyrene insulation	1,430	40,400	5,910	76,000	12.9
E. Brick and block cavity wall with 50 mm (2") fiberglass insulation 100 + 50 + 200 mm (4" + 2" + 8")	1,470	41,500	6,070	107,000	17.6
BUILDING AS CONSTRUCTED Precast concrete wall panels with 50 mm (2") polystyrene insulation plus 50 mm (2") fiberglass roof insulation	2,540	71,900	10,500	95,200	9.1

3.3 Subject Building As Constructed

The savings and first cost premium estimates for the subject building as compared to a base building are presented in Table 1.

3.4 Lighting Options

Lighting is another substantial consumer of energy. Most warehouse buildings are designed with fluorescent lighting. The case study building has 2.4 m (8 ft), 2 lamp industrial fixtures using 110 watt high output lamps.

Two alternate light sources could have been used to reduce energy consumption. Both metal halide and high pressure sodium are referred to as high intensity discharge sources and are particularly suitable for the 6.7 m (22 ft) clear height available.

Metal halide provides light with colour characteristics similar to mercury vapour and not unlike fluorescent for warehouse or light industrial applications. High pressure sodium lamps produce light with a yellow cast and are suitable for warehousing and most manufacturing facilities.

High pressure sodium lamps are not suitable if colour rendition is an important aspect of the user's operations. Because both types are more efficient (more light per unit of electric power consumed) and because they use higher output lamps, fewer fixtures are required. This makes fixture placement important in warehousing applications where racks and storage heights can interfere with the light distribution.

Tables 2 and 3 show the estimated savings and first cost premium for original installation of each of these sources to the basic building and to the building as built. The effect of operating the lights all the time or only when the building is occupied is also shown. The first cost for high pressure sodium is lower than for fluorescent due to the fewer fixtures required which reduces both fixture

LIGHTING MODIFICATIONS TO BASE BUILDING	REDUCTION IN ANNUAL ENERGY USE & COST				ESTIMATED FIRST COST PREMIUM $	SIMPLE PAYBACK PERIOD YEARS
	KWH ELECTRICITY	MCF GAS	M³ GAS	$		
A. Metal halide lighting in place of fluorescent - lights on at all times.	65,700	-140	- 3,900	1,990	3,200	1.6
B. Metal halide lighting in place of fluorescent - light off during unoccupied hours.	19,500	- 40	- 1,200	580	3,200	5.5
C. High pressure sodium lighting in place of fluorescent - lights on at all times.	207,600	-570	-16,100	5,750	-3,200	IMMEDIATE
D. High pressure sodium lighting in place of fluorescent - lights off during unoccupied hours.	61,600	-170	- 4,900	1,680	-3,200	IMMEDIATE

TABLE 2: DESIGN MODIFICATIONS TO LIGHTING SYSTEM
COMPARISON OF SAVINGS AND FIRST COST PREMIUM
- BASE BUILDING

LIGHTING MODIFICATIONS TO SUBJECT BUILDING	REDUCTION IN ANNUAL ENERGY USE & COST				ESTIMATED FIRST COST PREMIUM $	SIMPLE PAYBACK PERIOD YEARS
	KWH ELECTRICITY	MCF GAS	M^3 GAS	$		
A. Metal halide lighting in place of fluorescent - lights on at all times.	65,700	-180	- 5,100	1,820	3,200	1.8
B. Metal halide lighting in place of fluorescent - light off during unoccupied hours.	19,500	- 60	- 1,700	510	3,200	6.3
C. High pressure sodium lighting in place of fluorescent - lights on at all times.	207,660	-540	-15,400	5,850	-3,200	IMMEDIATE
D. High pressure sodium lighting in place of fluorescent - lights off during unoccupied hours.	61,600	-150	- 4,400	1,770	-3,200	IMMEDIATE

TABLE 3: DESIGN MODIFICATIONS TO LIGHTING SYSTEM COMPARISON OF SAVINGS AND FIRST COST PREMIUM - SUBJECT BUILDING

cost and installation cost. With metal halide, fewer fixtures are required than with fluorescent but the higher fixture and lamp unit costs are not offset completely by the lower installation cost.

A further advantage of the high intensity discharge sources is their higher average lamp life and reduced number of fixtures which will result in lower maintenance costs.

Tables 2 & 3 show reductions in annual energy use for electricity but also show increases in natural gas consumption. When the lighting system is on, the electrical energy is converted to heat and given up to the space. Less efficient systems use more electrical energy for the same light output and, provide more heat. Consequently, to establish the net effect of a more efficient lighting system, it is necessary to account for the increased energy consumption in the space heating system which occurs during the heating season. Because the building is not heated all year and because electric power is more expensive than natural gas for heating at this location, the net effect is a cost saving.

3.5 Operational Options

Two simple options have been studied for both the base building and the subject building. They relate to the operation of the building by the user rather than the design of the building. Whether the user is the owner or a tenant who pays the energy costs, these options will generally be cost effective. The two options are turning lights off and reducing space temperatures during unoccupied periods.

A. Turning lights off during unoccupied hours is a simple measure which costs nothing unless an automatic switching system is used, and yet the savings are more than most people anticipate. The case example has an occupied period of 10 hours per day for 5 days per week.

   Table 4 presents the data for the base building and Table 5 for the subject building.

B. Reduction of space temperatures in winter during unoccupied hours is a very cost effective measure, particularly if the number of unoccupied hours is high. The estimated cost shown for installing an automatic setback system for warehouse unit heaters is based on a single setback thermostat, located near the north-west corner of the building, controlling dual voltage relays in each unit heater circuit through a low voltage circuit.

The economics will be different depending on whether the building lights are left on during unoccupied hours or not. Item B in both Tables 4 and 5 presents the data for the situation where the lights are left on. The temperature is set back from 20°C (68°F) to 10°C (50°F) for 10 hours per day during the week and 24 hours per day for the weekend.

C. When the building lights are turned off during unoccupied hours and the temperature is set back simultaneously, the absence of heat gain from the lights has a negative effect on the gas consumption for heating. The cumulative savings for both actions are shown in item C for the base building in Table 4 and for the subject building in Table 5.

OPERATIONAL MODIFICATIONS TO BASE BUILDING	REDUCTION IN ANNUAL ENERGY USE & COST				ESTIMATED FIRST COST PREMIUM $	SIMPLE PAYBACK PERIOD YEARS
	KWH ELECTRICITY	MCF GAS	M^3 GAS	$		
A. Turn lights off during unoccupied hours.	251,000	-780	-22,200	6,540	0	IMMEDIATE
B. Set back space temperature from 20°C (68°F) to 10°C (50°F) during unoccupied hours lights left on.	0	1,930	54,700	8,000	1,500	0.2
C. Set back space temperature as above and turn lights off during unoccupied hours.	251,000	1,400	39,600	15,570	1,500	0.1

TABLE 4: OPERATIONAL BUILDING MODIFICATIONS
COMPARISION OF SAVINGS AND FIRST COST PREMIUM
- BASE BUILDING

OPERATIONAL MODIFICATIONS TO SUBJECT BUILDING	REDUCTION IN ANNUAL ENERGY USE & COST				ESTIMATED FIRST COST PREMIUM $	SIMPLE PAYBACK PERIOD YEARS
	KWH ELECTRICITY	MCF GAS	M^3 GAS	$		
A. Turn lights off during unoccupied hours.	251,000	-690	-19,700	6,910	0	IMMEDIATE
B. Set back space temperature from 20°C (68°F) to 10°C (50°F) during unoccupied hours lights left on.	0	900	25,500	3,730	1,500	0.4
C. Set back space temperature as above and turn lights off during unoccupied hours.	251,000	490	13,800	11,800	1,500	0.1

TABLE 5: OPERATIONAL BUILDING MODIFICATIONS
COMPARISION OF SAVINGS AND FIRST COST PREMIUM
- SUBJECT BUILDING

3.6 Original Design Versus Retrofit

Generally, it can be stated that energy efficiency should be considered at the design and construction stage since certain retrofit measures to conserve energy incur considerably higher costs and therefore longer payback periods.

Unfortunately, little attention has been paid in the past by building owners to design improvements which will incur a higher initial cost but which will reduce energy operating costs. Consequently, most warehouse and light industrial buildings have been constructed similar to the base building previously described.

After the building has been erected, the owner or a future owner may decide to investigate cost effective retrofitting options to reduce his energy consumption. In the case of roofs, walls and lighting systems, these options are very limited.

Roofs:

The addition of insulation to an existing roof, where the built-up roof is replaced over the added insulation, is an expensive procedure and not usually undertaken unless the existing roof has reached the end of its life or has failed and must be replaced.

An alternative approach is the IRMA or inverted roof construction where the roof membrane remains intact and styrofoam insulating board is added over the top, after removal of the loose gravel. After addition of the insulating board, either a lightweight stone ballast is added over a water-permeable fabric, or standard weight stone ballast is added on top of the insulation. Although this latter method is more economical for retrofit, the added weight of the stone ballast must be supported by the roof. Roof support steel is designed carefully according to snow loading requirements, and it is common to find that additional stone ballast cannot be supported. The long-term effect of trapped water on the roof membrane and on the insulation remains to be proven.

Exterior Walls:

The addition of insulation to existing exterior walls is not usually cost effective. Exterior application would require finishing panels and, unless the building requires a facelift, the economics are unfavourable. In certain cases where interior appearance is not important and wall damage is not likely, a low cost spray-on insulation or fiberglass covered with wire mesh may be suitable. If this interior finish is not acceptable, than a panel of gypsum board or other material must be applied on the inside of the added insulation. For warehouse applications, wall damage and deterioration make this approach risky.

Lighting:

Lighting is another substantial consumer of energy. Most of these buildings are constructed using fluorescent fixtures. Although this light source is reasonably efficient compared with incandescent sources, substantial gains in efficiency can be achieved by the use of metal halide or high pressure sodium sources. Once again, the retrofitting of efficient light sources is considerably more expensive than if installed initially.

4.1 General

Prospective owners of warehousing and light manufacturing facilities are not generally aware of the energy conservation options or economics which should form a basis for decisions on the planned building design. Many options are lost once the buildings have been constructed because the economics of retrofit are far less attractive.

For buildings which are constructed for leasing, the owner has little incentive to improve the energy efficiency under the present leasing arrangements.

This study has not attempted to examine all the economic implications or take into account the escalating cost of energy but only to show the present day costs and savings associated with certain measures as applied to the subject building.

4.2 Base Building Versus Subject Building

(i) The addition of 50 mm (2 in.) of fiberglass roof insulation reduces the current year's operating cost by $4600 at a first cost premium of $19,200, providing a simple payback of 4.2 years. Buildings constructed today usually include this thickness as a minimum. Increased thickness should be considered.

(ii) The use of precast concrete wall panels with 50 mm (2 in.) of polystyrene insulation reduces the current year's operating cost by $5910 at a first cost of $76,000. In the absence of any requirement for a better exterior building appearance, this measure is not attractive.

4.3 Other Conservation Options

(i) Of all the alternatives for wall construction examined, the 300 mm (12 in.) concrete block wall having the cores filled with vermiculite is the most economically attractive from a pure energy operating cost point of view. Reservations about achieved thermal resistance due to workmanship and long term performance due to moisture penetration preclude an unequivocal recommendation.

(ii) If the owner desires a more pleasing exterior appearance than can be achieved with concrete block construction, metal panels and precast concrete panels will be considered. Once the decision has been made to upgrade the walls, the added cost for insulation should be compared to the savings, and this should make the extra investment attractive.

(iii) High intensity discharge lighting sources should definitely be considered by both owner/users and developers. The interior height to the underside of roof support steel should be 4.3 m (14 ft) minimum and heights above 5.5 m (18 ft) provide favourable conditions. High pressure sodium sources offer the best economic return. However, if colour rendition is a concern, metal halide sources should be examined.

(iv) Turning off lights during unoccupied hours is desirable in any building. Manual methods are usually unreliable in the long term, so a timer-based system should be considered. In this case, there will be an implementation cost. A large number of unoccupied hours will obviously increase the economic benefits.

(v) Setback of temperatures during unoccupied hours should be done automatically and is usually cost effective.

The economics of several other energy conservation measures that are beyond the scope of this study warrant careful examination during the design phase.

1. Use of insulated shipping and exit doors.

2. Reduction of infiltration of outside air into the building through openings and cracks.

3. Site selection and building orientation.

4. Destratification of air within buildings with high floor to ceiling heights.

5. Reduction of controlled space temperatures in winter during occupied times.

6. Use of radiant heating for shipping and receiving areas.

7. Use of enclosed truck bays for shipping and receiving.

8. Use of air curtains at shipping and receiving doors.

9. Limit the use of windows in the building envelope.

10. Reduction or elimination of forced ventilation during unoccupied periods.

11. Indoor design temperatures lower than $68^{o}F$.

12. Use of electric fork lift trucks to avoid mechanical exhaust requirements.

4.4 Closing Remarks

Because this study examined a particular building in a particular location, the economic results relate to the energy sources used and the unit costs of that energy. Certainly, there are areas of the country which will show more or less favourable results. Where the heating energy source is oil at significantly higher prices than the gas for this building, further improvement of the building envelope will be justifiable.

With regard to the first cost premiums shown in the tables, the increased cost of the improved wall and roof construction only has been considered. As a building's heat loss rate is reduced, the size of heating and cooling equipment can also be reduced. This will result in some reduction in the first cost for that equipment, but this has not been included in those first cost premium figures. The net result would be a slightly lower first cost premium than shown.

POOR

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